

TRIAL CONSTRUCTION OF UHPC HIGHWAY BRIDGE

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Abstract

Since 2007, the Korea Institute of Construction Technology (KICT) implemented the SUPER Bridge 200 project intending to develop UHPC materials as well as technologies for its application to bridges. This paper evaluates the field applicability of UHPC through the trial construction of a bridge executed in the last stage of the project. Even if the trial bridge is featured by a span length of 11 m and width of 5 m, its construction necessitates all the technologies required for the construction of a UHPC bridge. The cross-section was designed so as to secure the constructability and to maximize the efficiency of UHPC material. This resulted in a superstructure with a weight reaching merely one third of conventional slab bridges. Owing to an efficient design and the know-how gathered in the fabrication of UHPC, the fabrication and erection processes of the UHPC girder were carried out easily. Consequently, it can be stated that the UHPC bridge technology developed in this research has matured to a level enabling its immediate application on field.

Résumé

Le KICT, institut coréen de la construction, a débuté le projet SUPER Bridge 200 en 2007 afin de développer des bétons fibrés à ultra-hautes performances (BFUP) ainsi que les technologies associées pour leur utilisation dans la construction d'ouvrages d'art. Cet article fait le bilan sur les possibilités d'application des BFUP au travers de la réalisation d'un ouvrage réalisé dans la dernière étape du projet. Malgré la portée modeste de l'ouvrage, 10 m, pour une largeur de 5 m, sa construction a nécessité la mise en œuvre de toutes les techniques nécessaires à la réalisation d'un ouvrage BFUP. La section transversale a été conçue pour faciliter la construction tout en optimisant l'utilisation du BFUP. Il en résulte une structure avec un poids propre égal au tiers de celui d'un pont dalle traditionnel. Grâce à cette conception optimale et au savoir-faire accumulé dans la production d'un BFUP, la fabrication et la construction de la structure poutre en BFUP ont été réalisées aisément. On peut donc en conclure que la technologie associée aux ponts en BFUP, développée dans ce projet de recherche, a atteint un degré de maturité suffisant pour des applications réelles.

1. INTRODUCTION

Interest on Ultra High Performance Concrete (UHPC) in Korea started with the construction of the Seonyu footbridge (Fig. 1). This bridge completed in 2002 using the French material ‘Ductal’ was erected for the centennial commemoration of the Korea-France amity. This initiated the research on UHPC in Korea. Especially, the Korea Institute of Construction Technology (KICT) developed the ‘K-UHPC’ exhibiting a compressive strength of 200 MPa and implemented continuous efforts for its application to real structures. These efforts resulted in the first pedestrian cable-stayed bridge using K-UHPC constructed in 2009 in the site of KICT (Fig. 2) [1].



Figure 1: Seonyu footbridge [1]



Figure 2: UHPC pedestrian cable-stayed bridge [1]

This paper presents the features of the trial construction of a real highway bridge conducted to verify the field applicability of K-UHPC materials and corresponding technologies for their application to bridges developed by KICT through the ‘SUPER Bridge 200’ project [1-6].

2. PLANNING AND DESIGN

2.1 Planning of the bridge

The highway bridge applying UHPC was planned for the crossing of the test canal in the KICT River Experiment Center in Andong, renowned for the folk village of Hahoe listed in the UNESCO World Heritage. The length of the bridge was thus set to 11 m corresponding to the width of the canal and its width to 5 m. Besides, a clearance of 0.95 m is required over the canal crossed by the bridge. This clearance is practically equal to the height of the existing embankment (1.0 m). Accordingly, the bridge was likely to fail in fulfilling its role due to the difference in the heights of the approach road and the bridge if the girder depth was not minimized. Minimizing the girder depth was thus the first design constraint. Moreover, the batch plant for the fabrication of the UHPC girder was located at a distance of 300 km from the site. This gave an additional design constraint which imposed to fabricate the segments

with a size appropriate for their transport and assembling on site. Fig. 3 illustrates the longitudinal drawing of the bridge reflecting these constraints.

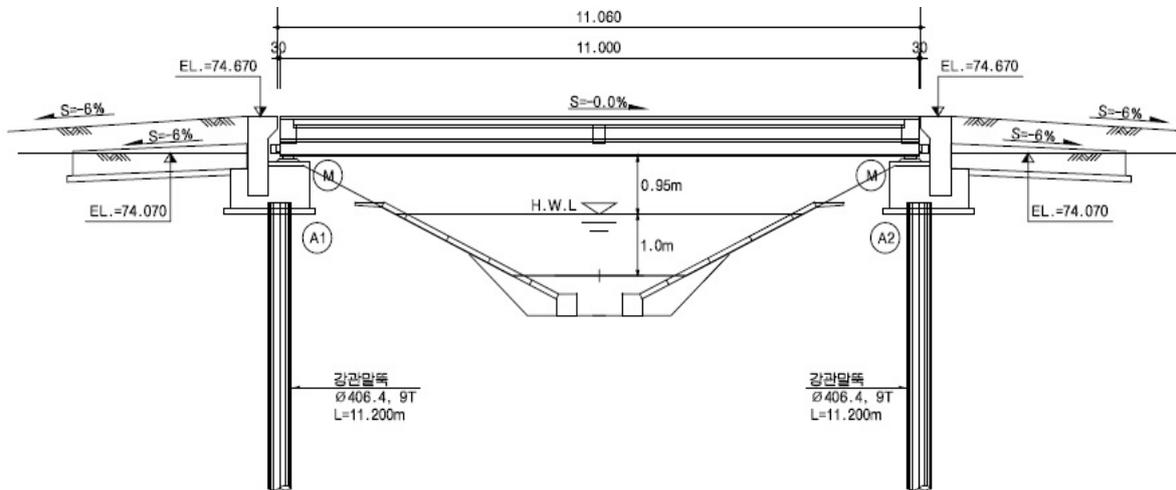


Figure 3: Longitudinal plan of the bridge

2.2 Characteristics of UHPC material

The UHPC material used in the design is ‘K-UHPC’ developed by KICT. Its composition is arranged in Table 1. The mechanical properties of UHPC are listed in Table 2. It should be noted that the design was conducted in compliance with the Design Guidelines for K-UHPC (2012) and the Highway Bridge Design Code of Korea (2010) [7,8].

Table 1: Composition of UHPC (by weight, except steel fibre)

W/B	Cement	Silica fume	Sand	Filling powder	Superplasticizer	Steel fiber (V_f)
0.2	1	0.25	1.1	0.3	0.018	2%

Table 2: Mechanical properties of UHPC

Design compressive strength	Design tensile strength	Elastic modulus	Poisson's ratio	Total shrinkage	Creep coefficient
180 MPa	9.5 MPa	45 GPa	0.2	600×10^{-6}	0.45

2.3 Design of the bridge

Fig. 4 shows the cross-section of the bridge design with respect to the design constraints. The girder and slab were designed to form a monolithic π -shape cross-section so as to minimize the girder depth. The superstructure was composed of 3 segments to ease its transport. From the final design, each segment was dimensioned with a length of 11 m, width of 1.68 m and depth of 0.6 m. This resulted in segments with a weight of merely 112 kN requiring relatively small equipment for their transport and erection. For comparison, a reinforced concrete (RC) slab bridge for a bridge with similar dimensions would have required a thickness of approximately 800 mm. The designed UHPC π -girder presents thus a depth reaching 75% of that of a RC slab for a weight representing only one-third. The

resulting girder is combining adequately the material advantages of UHPC together with the structural efficiency of the π -girder. A series of 7 steel strands with diameter of 15.2 mm were disposed in each web of the π -girder to introduce prestress by post-tensioning.

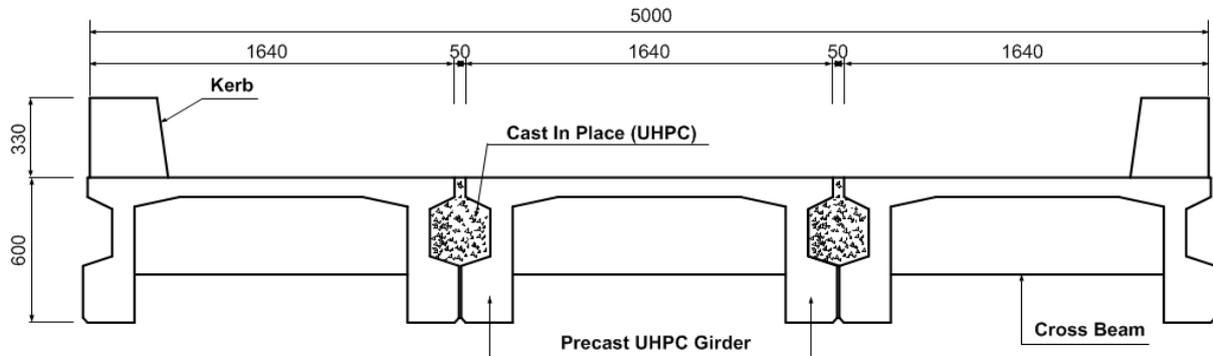
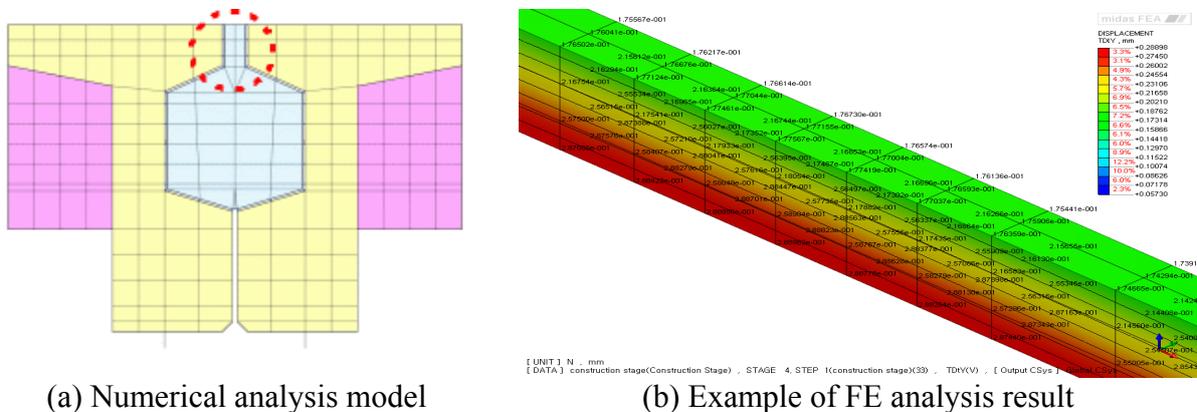


Figure 4: Cross-section of the bridge

2.4 Detailed check of connections

The thickness of the slab was set to 100 mm. A core was arranged in the connection between the precast members for the transfer of the shear force. In addition, cast-in-place UHPC was chosen as filling material. Transverse steel bars were installed in the cross beams to achieve the monolithic girder. Since the evaluation of the behaviour of the slab and connections was difficult through the analysis of an ordinary frame, three-dimensional FE analysis was executed for the design of the connections.



(a) Numerical analysis model

(b) Example of FE analysis result

Figure 5: Detailed check of connections

3. FABRICATION AND CONSTRUCTION

3.1 Fabrication of girder

UHPC was fabricated in the batch plant at KICT. The three segments exhibited identical shape and were symmetric with respect to the longitudinal axis. Therefore, the form shown in Fig. 6 was manufactured and used repeatedly for the three segments. Fig. 7 illustrates the placing of UHPC. After placing, the segments were subjected to steam curing followed by the

stripping of the form (Fig. 8). Then, prestress was applied longitudinally using a mono-jack (Fig. 9) to complete the fabrication of the girder segments.

3.2 Construction of substructure

During the fabrication of the UHPC π -girder at the batch plant, the construction of the substructure was conducted on site. The soil conditions on site being unfavorable, pile foundations were applied as shown in Figure 10. Figure 11 displays the construction of the abutment.



Figure 6: Assembling of form



Figure 7: Placing of UHPC



Figure 8: After the stripping of the form



Figure 9: Longitudinal prestressing



Figure 10: Driving of piles



Figure 11: Construction of abutment

3.3 Erection of superstructure

The so-fabricated three girder segments were transported on site 300 km far away from the batch plant. The segments were then installed on the abutments using a 1000 kN-crane as shown in Fig. 12. The installation took only 30 minutes for the 3 segments without any trouble during the operation. The specially fabricated movable UHPC mixer shown in Fig. 14 was used to place UHPC in the connections between the segments (Fig. 15). The capacity of the mixer being 0.5 m³, the mixing and placing process was repeated two times to fill the 0.42 m³ of each connection. The whole process was completed in approximately two hours. The works were performed outdoor and the weather was very hot at the time. Such environmental conditions degraded slightly the flowability of UHPC but without affecting the quality.



Fig. 12: Lifting and installation of girder



Fig. 13: Installed girder



Fig. 14: Moveable batch



Fig. 15: Placing of UHPC in connections

One week of waiting was necessary until the connection-filling UHPC developed sufficient strength. Thereafter, the steel bars were tensioned using the sheath tubes arranged in advance in the cross beams (Fig. 16). This process completed the connection of the segments. The adopted steel bars presented diameter of 32 mm and no particular problem occurred during the tensioning. Fig. 17 illustrates the completed bridge.



Fig. 16: Tensioning of steel bar



Fig. 17: Completed bridge

4. CONCLUSIONS

A highway bridge was erected for the first time in Korea using the UHPC developed by KICT. Even if this bridge presents relatively small dimensions with a length of 11 m, its construction necessitated the application of all the technologies required for the construction of a bridge. In other words, the erection of the bridge involved the technology related to the materials and fabrication of UHPC, the design technology of UHPC bridges, the fabrication and erection technology of segments, and the construction technology of connections, which gather all the technologies necessary for the construction of bridge structures. The trial construction of the bridge enabled to complete the validation of all these processes and demonstrated that the UHPC bridge technology developed through the ‘SUPER Bridge 200’ project by KICT has reached a level enabling its immediate application on field.

ACKNOWLEDGEMENTS

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